# Beam Stability Requirements for Low Emittance Storage Rings

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*1st Workshop on Low Emittance Lattice Design*

*hosted by ALBA, at the Autonomous University of Barcelona*

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- SR beam parameters and stability criteria
- Photon-electron relationships
- Electron beam properties
- Stability time scales
- Basic stability requirements
- Examples of stabilizing technology

# SR Beam Parameters

**Photon beam parameters of interest to experimenter include:**

- position and pointing accuracy on small apertures and samples
- beam size

  **both of these affect intensity constancy at the sample**
- angle and divergence at optical components and sample

  **contribute to resolution of energy, scattering angle, intensity**
- energy and energy bandwidth

  **contribute to energy resolution of experiment**
- photon pulse time-of-arrival and bunch length

  **for timing experiments**
- polarization
- coherence
- lifetime
- …..

**Beam stability characterized in 6-D phase space:** (x, x′, y, y′, E, t)

# Beam Stability Criteria

**Beam stability requirements depend on:**

- beam line optical configuration and apertures
- sample size
- measurement technique and instrumentation
- data acquisition time scale
- data averaging and processing methods

**Stability is relative:**

- flux constancy with respect to apertures within the 6-D acceptance phase space of the experiment

**While stability requirements vary, generic requirements can be estimated from criteria common to many experiments**

# Beam Stability Criteria – cont.

**Today, sources of photon beam instability can be divided into 2 categories:**

- those associated with beam line optical components and experimental apparatus

**the beam line staff's problem!**

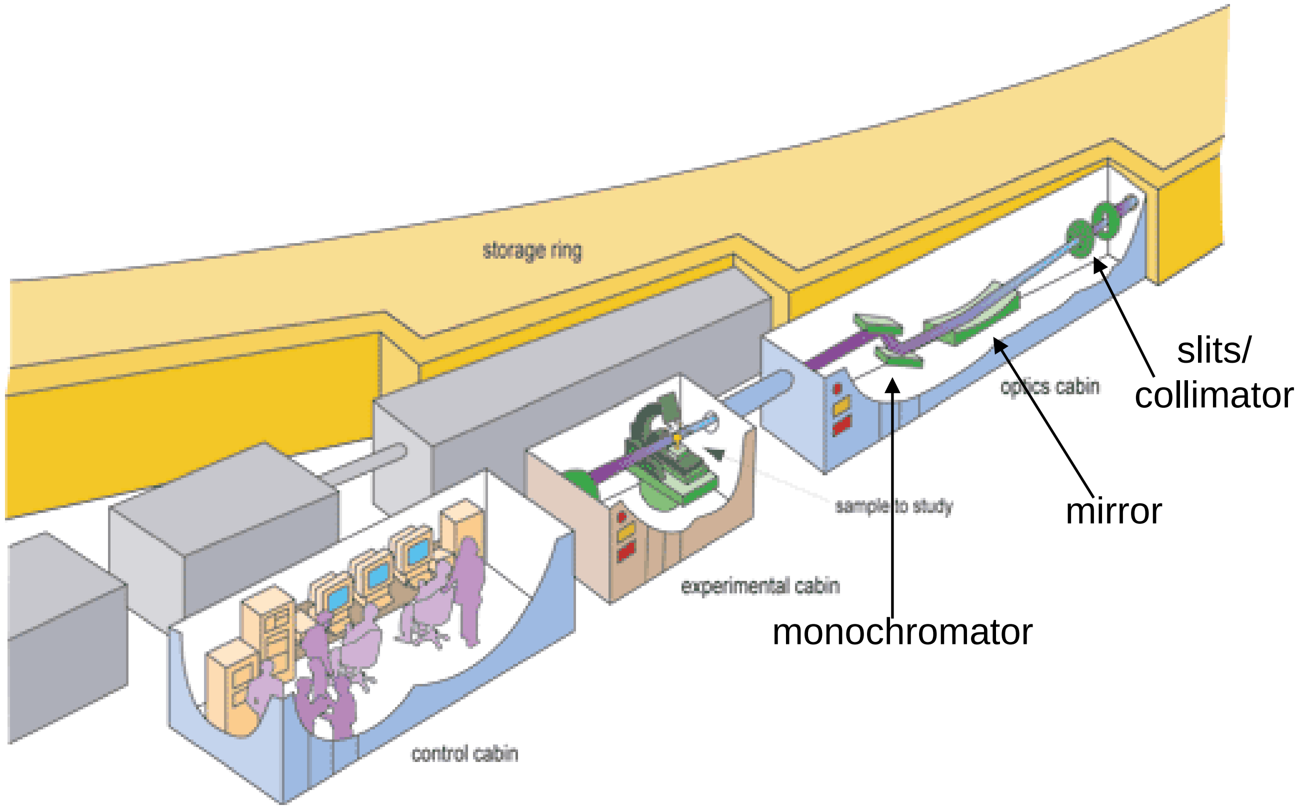
- those associated with the electron beam

**the accelerator staff's problem!**

**In the future, especially for 4GSRs, accelerator and beam line stability should be a joint challenge, perhaps requiring integrated stabilizing systems**

**meeting stability requirements will be everyone's problem!**

# SR Generic Beam Line



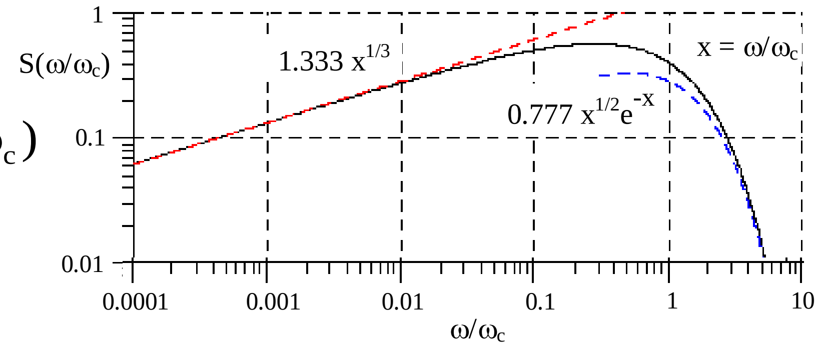

**could be more apertures (slits, etc) than shown**

# Photon-Electron Relationships – Photon Emission

K-J Kim

## Dipole spectral flux density (per horizontal mrad, integrated over vertical angle):

$$\frac{dF_{dip}(\omega)}{d\theta} = 2.457\,x10^{16}\,\frac{\Delta\omega}{\omega}\,E_{e-}{}^{2}(GeV)\,I(A)\,S(\omega/\omega_c)$$



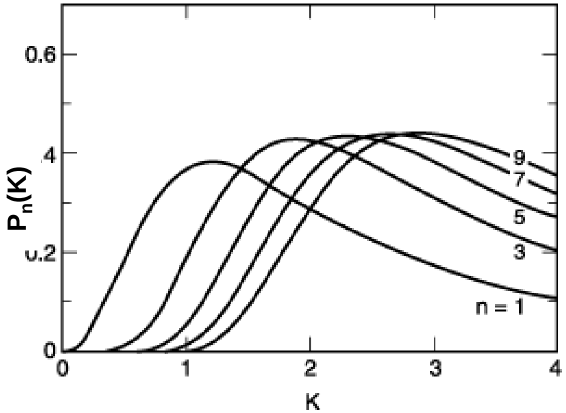

## Wiggler spectral flux density:

$$\frac{dF_{wigg}(\omega)}{d\theta} =\sim N_{wigg}\,\frac{dF_{dip}(\omega)}{d\theta} \qquad N_{wigg} = \#\,wiggler\ \ poles$$

## Undulator spectral flux density:

$$\left.\frac{d^2F_{und}(\omega_n)}{d\theta\,d\varphi}\right|_{\varphi,\theta=0} = 1.744\,x10^{14}\,\frac{\Delta\omega}{\omega}\,N_u{}^{2}E_{e-}{}^{2}(GeV)\,I(A)\,P_n(K)$$

$N_u$ = # undulator periods



# Photon-Electron Relationships – cont.

## Photon beam divergence:

$\sigma'_{ph}(L) = \sigma'_{ph}(0) = [\sigma'_{e-}{}^2 + \sigma'_{\Psi}{}^2]^{1/2}$

$\sigma'_{e-} = [\varepsilon\gamma(s) + (\eta'\delta)^2]^{1/2}$

**for dipoles and wigglers:**

$$\sigma'_{\Psi}(\lambda) \cong \begin{cases} \dfrac{1.07}{\gamma}\left(\dfrac{\lambda}{\lambda_c}\right)^{1/3} & \lambda \gg \lambda_c \\ \dfrac{0.64}{\gamma} & \lambda = \lambda_c. \\ \dfrac{0.58}{\gamma}\left(\dfrac{\lambda}{\lambda_c}\right)^{1/2} & \lambda \ll \lambda_c \end{cases}$$

$$\lambda_c = \frac{2\pi c}{\omega_c} = \frac{hc}{E_c} \qquad h = \text{Planck's const.}$$

$= 4.14 \times 10^{-18}$ keV-s

$$E_c(\mathrm{keV}) = \frac{3\hbar c\gamma^3}{2\rho} = 0.665\, B(T)\, E^2(\mathrm{GeV})$$

**for planar undulators:**

**(on-axis, central cone)**

$$\sigma'_{\Psi}(n) = \sqrt{\frac{\lambda_n}{L_u}} = \frac{1}{\gamma}\left[\frac{\lambda_u(1+K^2/2)}{2nL_u}\right]^{1/2} = \frac{1}{\gamma}\left[\frac{1+K^2/2}{2nN_u}\right]^{1/2}$$

n = harmonic # $L_u$ = undulator length $\lambda_u$ = undulator period $N_u$ = # periods K = ~1

# Photon-Electron Relationships – Photon Energy

## Dipole critical energy:

$$E_{crit\,dip}(keV) = \frac{h}{2\pi}\,\omega_c = 0.665 B(T) E_{e-}^{\;2}(GeV)$$

## Wiggler critical energy:

$$E_{crit\,wigg}(\theta) = E_{crit\,dip}\left[1 - \left(\frac{\theta\gamma}{K}\right)^2\right]^{1/2}$$

where $\theta$ is horizontal viewing angle,

$K = \delta/\gamma^{-1}$, ratio of wiggler deflection angle $\delta$ to beam opening angle

## Undulator harmonics:

$$E_n(keV) = 0.95\frac{nE_{e-}^{\;2}(GeV)}{\lambda_u(cm)}\left(\frac{1}{1 + K^2/2 + (\gamma\theta)^2}\right) \qquad \frac{\Delta E_n}{E_n} = \frac{1}{nN_u}$$

n = harmonic number $\lambda_u$ = undulator period $N_u$ = # periods $\theta$ = hor or vert view angle

**for zero-emittance, zero-energy-spread electron beam**

# Undulator Radiation

## Angular distribution of 1st harmonic:

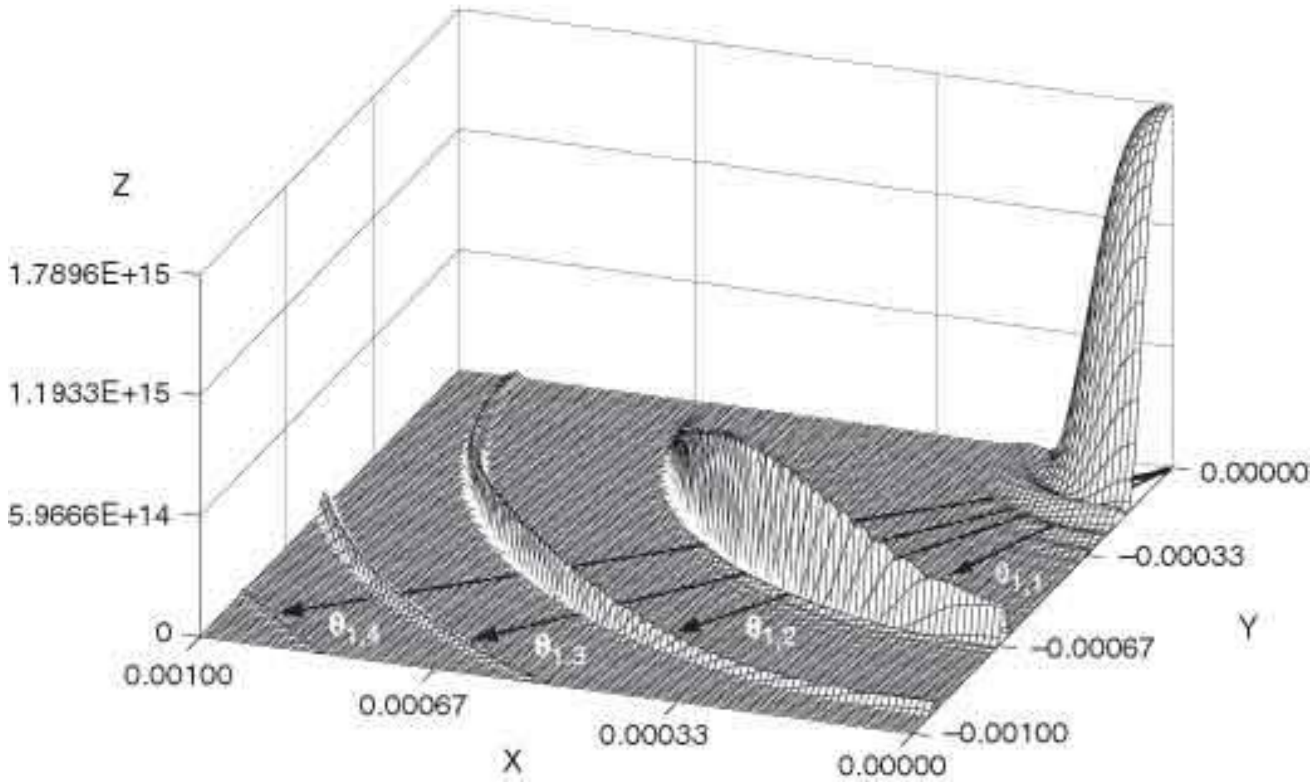
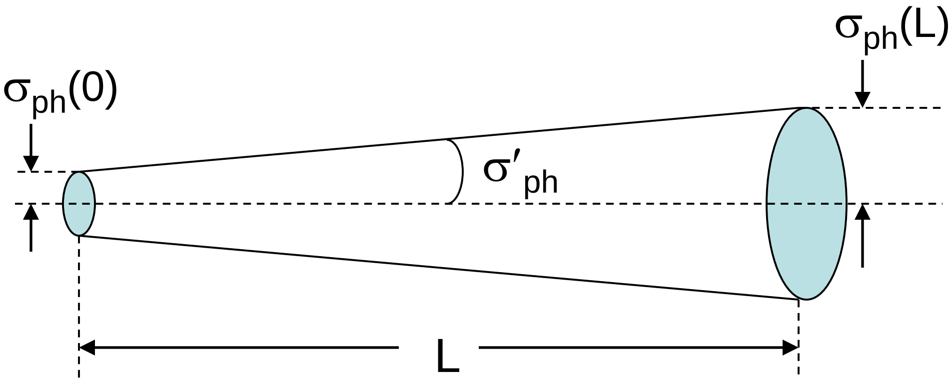



***Fig. 2-5.*** *The angular distribution of fundamental (n = 1) undulator radiation for the limiting case of zero beam emittance. The x and y axes correspond to the observation angles θ and ψ (in radians), respectively, and the z axis is the intensity in photons·*$s^{-1}\cdot A^{-1}\cdot(0.1\ mr)^{-2}\cdot(1\%\ bandwidth)^{-1}$*. The undulator parameters for this theoretical calculation were N = 14, K = 1.87,* $\lambda_u$ *= 3.5 cm, and E = 1.3 GeV. (Figure courtesy of R. Tatchyn, Stanford University.)*

K-J Kim, from X-ray Data Booklet, LBNL

# Photon-Electron Relationships

## Photon beam size:




- unfocused, vertical plane:

  (assume depth of field = 0)

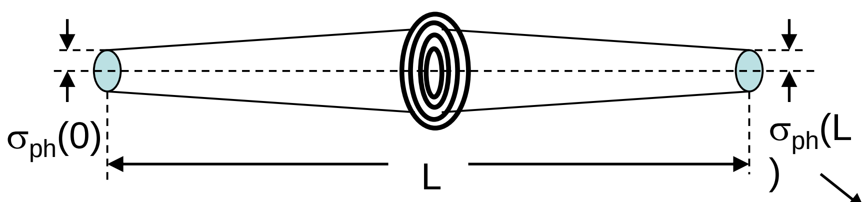
  $$\sigma_{ph}(L) = [\sigma_{ph}(0)^2 + L^2\sigma_{ph}'^2]^{1/2}$$

  $$\sigma_{ph}(0) = [\sigma_{e-}^2 + \sigma_{diff}^2(\lambda)]^{1/2}$$

**i.e the convolution of electron beam size and diffraction-limited apparent size of a single electron (quadrature sum of 2 Gaussian distributions).**

$$\sigma_{diff} = \frac{\lambda}{4\pi\sigma'_{\Psi}(\lambda)} \qquad \left(\sigma_{diff} = \frac{\lambda}{2\pi\sigma'_{\Psi}(\lambda)}\right)$$

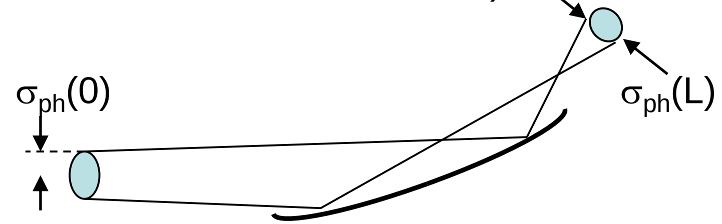
$$\sigma_{e-} = [\varepsilon\beta(s) + (\eta(s)\delta)^2]^{1/2}$$




- focused (1:m, m = magnification):

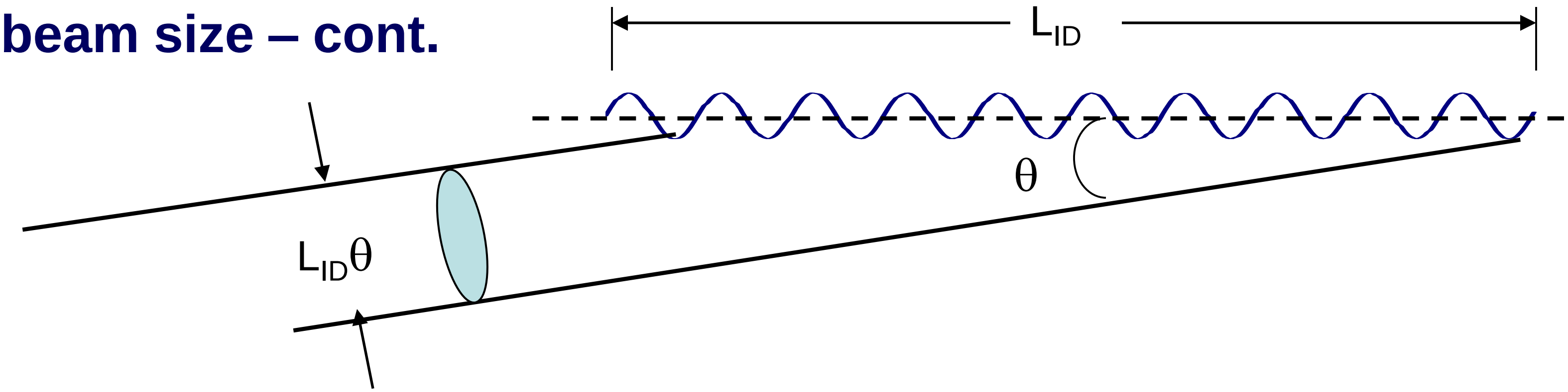
  $$\sigma_{ph}(L) = m\sigma_{ph}(0)$$ **(~insensitive to angle)**

  $$\sigma'_{ph}(L) = -\sigma'_{ph}(0)/m$$



# Photon-Electron Relationships – cont.

## Photon beam size – cont.




- Off-axis view of ID radiation adds to focused beam size due to extended source
- On-axis beam size has additional terms arising from wiggle amplitude and ID length:

$$\sigma_{Tx}^2 = \sigma_r^2 + \sigma_x^2 + a^2 + \tfrac{1}{12}\sigma_{x'}^2 L^2 + \tfrac{1}{36}\varphi^2 L^2 \qquad \sigma_{Tx'}^2 = \sigma_{r'}^2 + \sigma_{x'}^2$$

$$\sigma_{Ty}^2 = \sigma_r^2 + \sigma_y^2 + \tfrac{1}{12}\sigma_{y'}^2 L^2 + \tfrac{1}{36}\psi^2 L^2 \qquad \sigma_{Ty'}^2 = \sigma_{r'}^2 + \sigma_{y'}^2$$

from I.V.Bazarov

- DIpole source size is slightly increased from finite depth of field and orbit arc

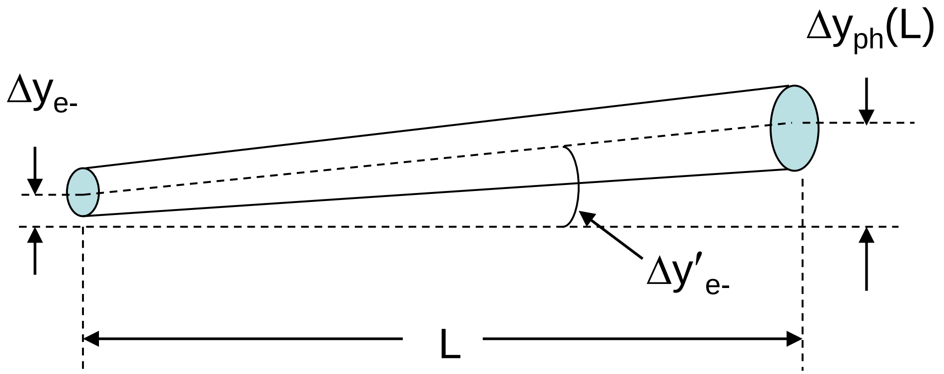
# Photon-Electron Relationships – cont.

## Beam line steering:

- pointing parameters (1st order) for **unfocused** photon centroid:

$$\Delta y_{ph}(L) = \Delta y_{e-} + L\Delta y'_{e-}$$

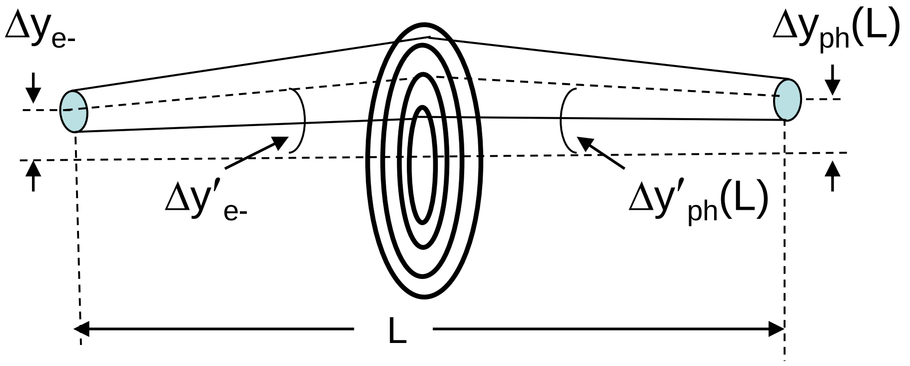
$$\Delta y'_{ph}(L) = \Delta y'_{e-}$$



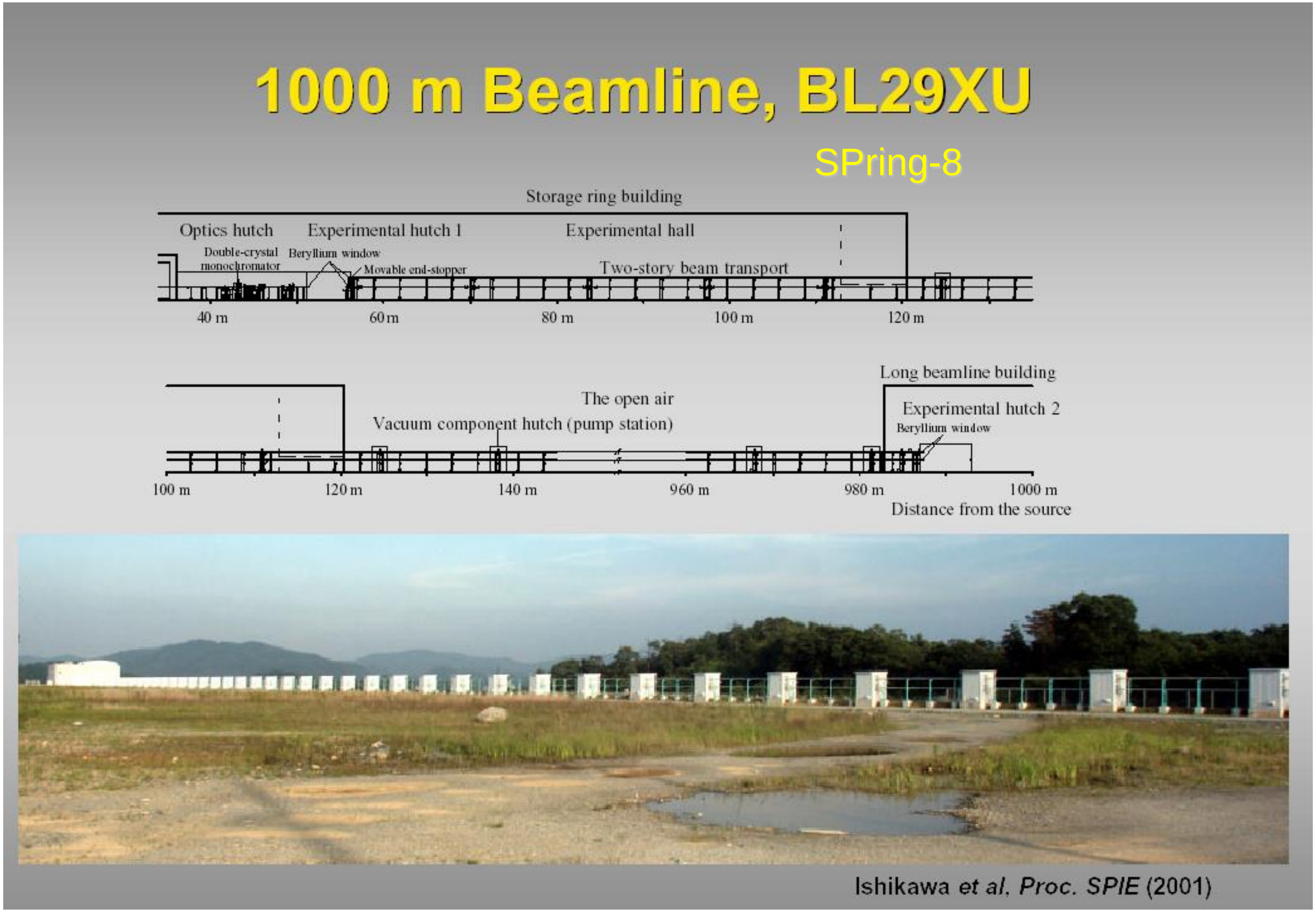

- **focused** (1:m) photon centroid:

$$\Delta y_{ph}(L) = m\Delta y_{e-}$$

$$\Delta y'_{ph}(L) = -\Delta y'_{e-}/m$$



# L is large in some cases…..



# Electron Beam Properties

**Electron beam characterized by conjugate variable pairs in 6-D phase space:**

| | | |
|---|---|---|
| **x, x′** | **y, y′** | **E, t (or $\phi$)** |
| **-------- transverse ----------** | | **longitudinal** |

**For each conjugate pair, beam occupies phase space ellipse of constant area - or emittance (A = $\pi\varepsilon$)**

transverse:

$$\varepsilon = \gamma(s)x^2 + 2\alpha(s)xx' + \beta(s)x'^2 = \text{constant}$$

$$\varepsilon_y \cong k\varepsilon \quad (k = \text{coupling},\ k <\sim 0.1)$$

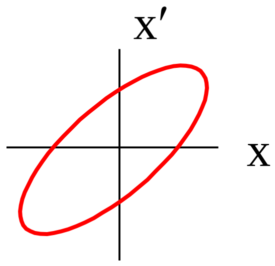
$$\left(\alpha = -\beta'/2 \qquad \gamma = \frac{1+\alpha^2}{\beta}\right)$$

e- beam size:

$$\sigma_x(s) = \sqrt{\varepsilon_x \beta_x(s) + (\eta(s)\delta E/E)^2} \qquad \sigma_y(s) = \sqrt{\varepsilon_y \beta_y(s)}$$

e- divergence:

$$\sigma_{x'}(s) = \sqrt{\varepsilon_x \gamma_x(s) + (\eta'(s)\delta E/E)^2} \qquad \sigma_{y'}(s) = \sqrt{\varepsilon_y \gamma_y(s)}$$




longitudinal:

$$\Delta\phi\ (\text{rad}) = \frac{h\alpha_c}{\nu_s}\frac{dE}{E} \quad \left(= \sim 30\frac{dE}{E}\ \text{for APS-U}\right)$$

# Electron Beam Properties – cont.

**Have coupling between phase space planes:**

- H-V by skew quads, orbit in sextupoles, resonances, ID changes
- longitudinal-transverse (energy-orbit, $\Delta x = \eta \Delta E/E$)
- photon energy dependent on orbit through IDs
- photon polarization dependent on vertical orbit through dipole
- etc.

# Experiment Sensitivity to Electron Beam Parameters

**Response of experiment observable parameters to source point electron beam parameters:** sensitivity matrix M(i,j)

$$[\Delta P_{exp}(i)] = \mathbf{[M(i,j)]}\ [\Delta P_{e-}(j)]$$

where

$$[\Delta P_{exp}(i)] = \begin{pmatrix} \Delta I_{ph} \\ \Delta E_{ph} \\ \Delta E_{ph}/E_{ph}\ (\mathrm{rms}) \\ \Delta\sigma_x \\ \Delta\sigma_y \\ \Delta\sigma'_x \\ \Delta\sigma'_y \\ \Delta\sigma_z \\ \Delta x \\ \Delta y \\ \Delta x' \\ \Delta y' \\ \Delta t_{bunch} \\ \text{polarization} \\ \text{coherence} \end{pmatrix}$$

$$[\Delta P_{e-}(i)] = \begin{pmatrix} \Delta I_{e-} \\ \Delta E_{e-} \\ \Delta E_{e-}/E_{e-}\ (\mathrm{rms}) \\ \Delta\sigma_x \\ \Delta\sigma_y \\ \Delta\sigma_z \\ \Delta\sigma'_y \\ \Delta\sigma_z \\ \Delta\theta_{rot} \\ \Delta x \\ \Delta y \\ \Delta x' \\ \Delta y' \\ \Delta t_{\ bunch} \end{pmatrix}$$

# Relationship Between Photon and Electron Parameters

TABLE II. Relationship of photon and electron parameters (approximate, with constant lattice Twiss parameters; $\gamma_s$ is Twiss parameter; $N_u$ = number of undulator periods; $n$ = undulator harmonic number).

| Photon parameter | Relationship to electron parameters |
|---|---|
| 1. Size at $L$ | $\sigma_{ph}(L)=[\sigma_{e^-}^{2}+\sigma_{diff}^{2}(\lambda)+(L\sigma'_{ph})^2]^{1/2}$ (unfoc)<br>$\sigma_{ph}(L)=\sigma_{ph}(0)$ (1:1 foc)<br>$\sigma_{diff}(\lambda)=\lambda/[4\pi\sigma'_{\psi}(\lambda)]$  $\sigma_{e^-}=[\epsilon\beta(s)+(\eta(s)\delta E/E)^2]^{1/2}$ |
| 2. Divergence at $L$ | $\sigma'_{ph}(L)=\sigma'_{ph}(0)=[\sigma'^{2}_{e^-}+\sigma'^{2}_{\psi}]^{1/2}$ (unfoc)<br>$\sigma'_{ph}(L)=-\sigma'_{ph}(0)$ (1:1 foc)<br>$\sigma'_{e^-}=[\epsilon\gamma_s+(\eta'\delta E/E)^2]^{1/2}$  $\epsilon\propto E^2$<br>$\sigma'_{\psi}\propto\gamma_{e^-}^{-1}$ (dip wigg)  $\sigma'_{\psi}\propto\gamma_{e^-}^{-1}(nN_u)^{-1/2}$ (und) |
| 3. Position at $L$ | $\Delta y_{ph}(L)=\Delta y_{e^-}+L\Delta y'_{e^-}$ (unfoc)  $\Delta y_{ph}(L)=\Delta y_{e^-}$ (1:1 foc)<br>$\Delta y_{e^-}(\Delta E_{e^-})=\eta\Delta E_{e^-}/E_{e^-}$ |
| 4. Angle at $L$ | $\Delta y'_{ph}(L)=\Delta y'_{e^-}$ (unfoc)  $\Delta y'_{ph}(L)=-\Delta y'_{e^-}$ (1:1 foc)<br>$\Delta y'_{e^-}(\Delta E_{e^-})=\eta'\Delta E_{e^-}/E_{e^-}$ |
| 5. Critical freq/ undulator harm | $\omega_c\propto E_{e^-}^{2}$ (dip) $\omega_c\propto E_{e^-}^{2}[1-(\theta\gamma/K)^2]$ (wigg), $\theta$ = horiz view ang<br>$\omega_n\propto nE_{e^-}^{2}/[1/2+K^{-2}+(\theta\gamma/K)^2]$ (und)  $K/\gamma$ = ID deflect ang |
| 6. Energy/freq resolution | $\Delta E_{ph}/E_{ph}=\Delta y'_{ph}/\theta_B$ (xtal mono; $\theta_B=\sim 90-900$ mrad)<br>$\Delta\omega_n/\omega_n=1/nN_u$  (undulator) |
| 7. Spectral flux density | $dF(\omega)/d\theta\propto E_{e^-}I_{e^-}S(\omega/\omega_c)$ (dip, wigg on-axis; $S(\omega/\omega_c)$ in Fig. 3)<br>$dF(\omega_n)/d\psi d\theta\propto I_{e^-}/\sigma'^{2}_{ph}(\omega_n)$ (und, on-axis)<br>$F(\omega)$ = photons//s/unit freq BW; $I_{e^-}=e^-$ curr |
| 8. Bunch length | $\sigma_t(\alpha/\omega_s)\delta E_{e^-}/E_{e^-}$  $\alpha$ = moment. compact, $\omega_s$ = synchrotron freq |
| 9. Bunch time osc | $\Delta t_b=\Delta\phi/\omega_{rf}=(\alpha/\omega_s)\Delta E_{e^-}/E_{e^-}$  $\omega_{rf}$ = rf frequency |

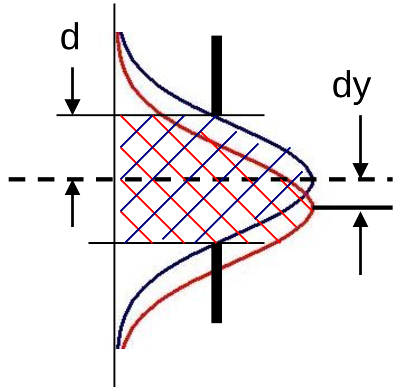
$$\alpha=-\beta'/2$$

$$\gamma_s=\frac{1+\alpha^2}{\beta}$$

$$\gamma_{e-}=\frac{E_{e-}}{m_{e-}c^2}$$

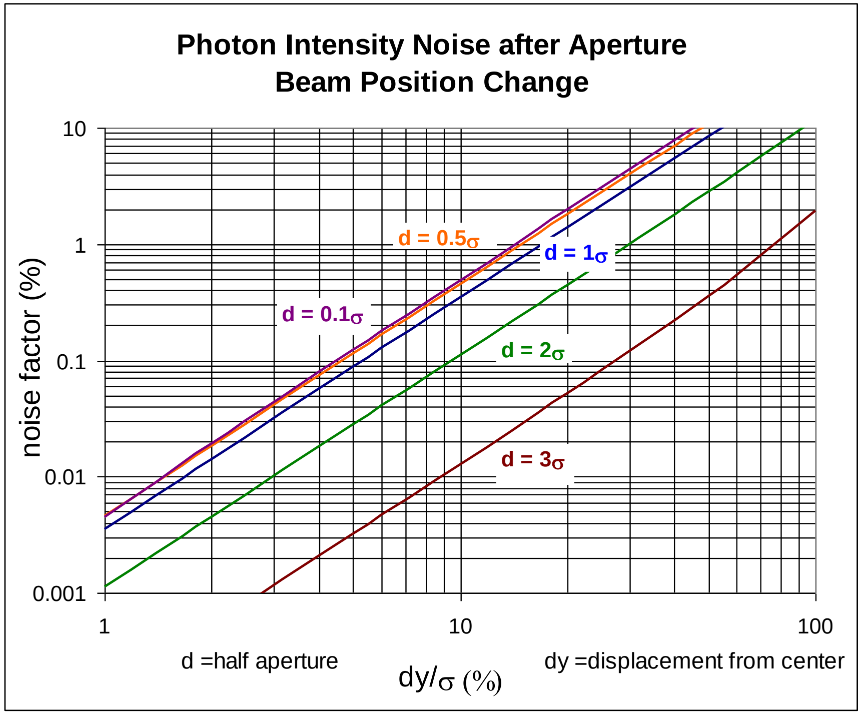
# Intensity Stability after Apertures

## Sensitivity of intensity (flux) to beam position change:




$$F_{y=0} = \frac{F_{tot}}{\sqrt{2\pi}\sigma_y} \int_{-d}^{d} e^{\frac{-y^2}{2\sigma_y^2}} dy$$

$$F_{y=dy} = \frac{F_{tot}}{\sqrt{2\pi}\sigma_y} \int_{-d}^{d} e^{\frac{-(y-dy)^2}{2\sigma_y^2}} dy$$



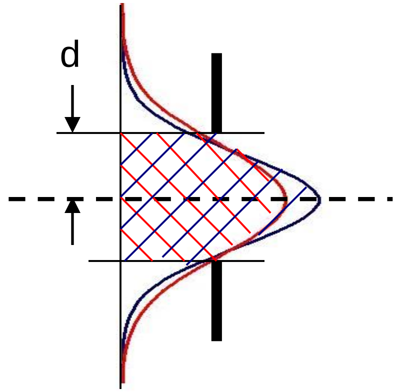

$F_{tot}$ = total flux in Gaussian beam before aperture

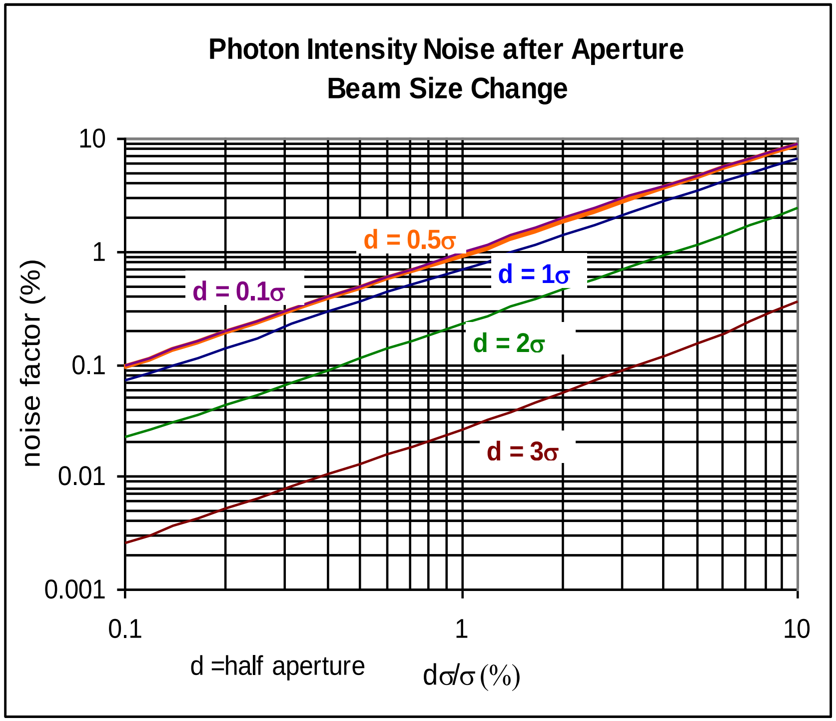
"noise factor" = $|F_0 - F_{dy}|/F_0$ **~ $dy^2$**

For noise factor (intensity stability) <0.1%, **dy < 5% $\sigma_y$** **(<1.5% $\sigma_y$ for 0.01% stability)**

# Intensity Stability after Apertures - cont.

## Sensitivity of intensity (flux) to beam size change:




$$F_{\sigma_0} = \frac{F_{tot}}{\sqrt{2\pi}\sigma_0} \int_{-d}^{d} e^{\frac{-y^2}{2\sigma_0^2}} dy$$

$$F_{\sigma_0+d\sigma} = \frac{F_{tot}}{\sqrt{2\pi}(\sigma_0 + d\sigma)} \int_{-d}^{d} e^{\frac{-y^2}{2(\sigma_0+d\sigma)^2}} dy$$

noise factor = $|F_{\sigma 0}-F_{\sigma 0+d\sigma}|/F_{\sigma 0}$ **~ dσ**

For noise factor (intensity stability) <0.1%, **dσ < 0.1% $\sigma_y$**

**(<0.01% $\sigma_y$ for 0.01% stability)**

# Source Stability Relationships

**Can derive basic some basic relationships experimental observables and beam properties based simple (1st-order) dependencies (-- = 2nd order):**

| parameters | e- orbit | e- size/ rotation | e- energy/ energy spread (& RF stability) | ID field (esp EPUs) |
|---|---|---|---|---|
| intensity (pointing, beam size, emission) | x | x | x | x |
| energy and energy resolution | x | x (dispersive monos) | x | x |
| timing, bunch length | -- (pseudo 1-bunch?) | x | x | -- |
| polarization | x (dipole, EPU) | -- | -- | x |
| coherent fraction | -- | x | x ID high harmonics | -- |

Not included: accelerator lattice stability, lifetime stability, other

# Some Electron Orbit- and Size-Perturbing Mechanisms

## Long term (weeks-years):

- ground settlement (mm)
- seasonal ground motion (< mm, sometimes more)

## Medium term (minutes-days):

- diurnal temperature (1-100 μm)
- crane motion (1-100 μm)
- fill patterns (1-100 μm)
- coupling changes
- river, dam activity (1-100 μm)
- machine fills (heating, BPM intensity dependence)
- RF drift (microns)
- gravitational earth tides (ΔC = 10-30 μm)

## Short term (milliseconds-seconds):

- ground vibration, traffic, trains, etc. (< microns, <50 Hz typ)

  ground motion amplified by girder + magnet resonances (x~20 if not damped) and by lattice (x ~5+)

  **⇒ nm level ground motion can be amplified close to μm level**
- cooling water vibration (microns)
- booster operation (microns)
- power supplies (microns)
- rotating machinery (air conditioners, pumps) (microns)
- insertion device changes (1-100 μm)
- vac chamber vibration from BL shutters, etc. (microns)

## High frequency (sub-millisecond):

- high frequency PWM and pulsed power sources (microns)
- synchrotron oscillations (1-100 μm)
- single- and multibunch instabilities (1-100 μm)
- gas bursts, ions, dust, …..

# Electron Orbit Noise Spectra

Integrated noise spectra
G. Rehm, SRI 2012

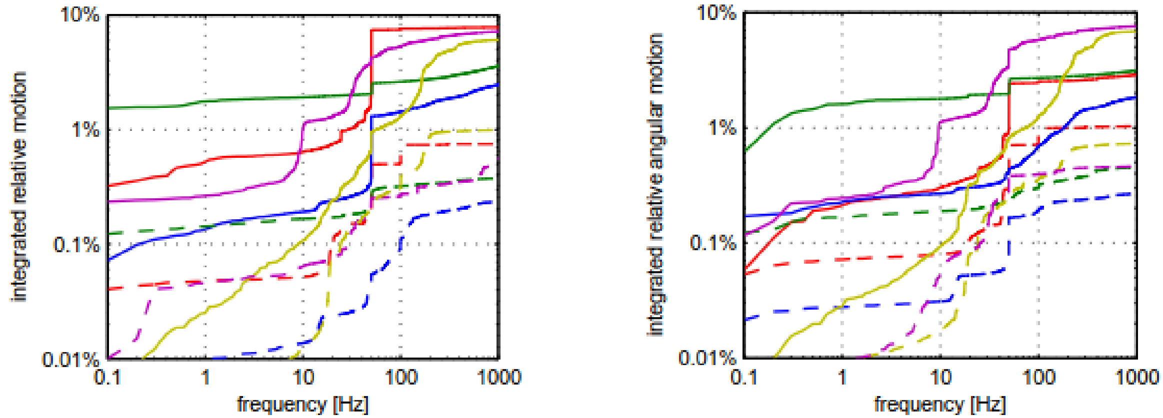



**Figure 1.** Integrated motion (left) and angular motion (right) relative to the respective vertical (solid) and horizontal (dashed) beam sizes: ALBA (green), Australian Synchrotron (ASLS) (red), ESRF (purple), Diamond Light Source (DLS) (yellow), Soleil (blue)

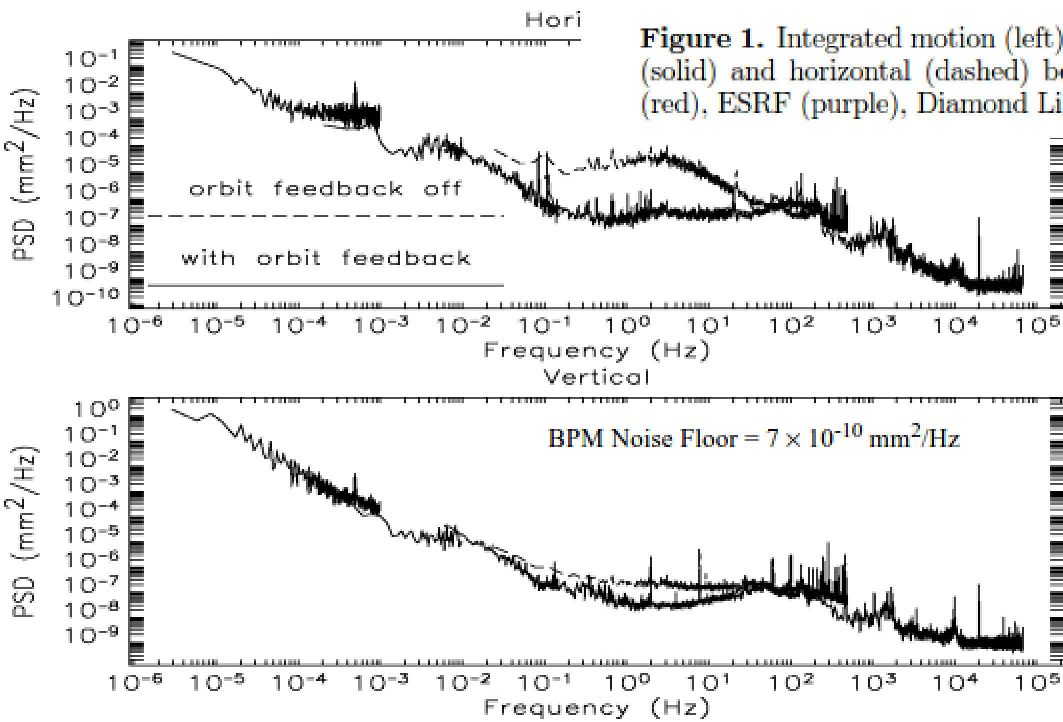



**FIGURE 1.** Horizontal and vertical APS beam motion power spectral densities.

Power spectral density
courtesy G. Decker et al.

# Beam Stability Time Scales

- **Disturbance time scale << experiment integration time:**

  Orbit disturbances blow up effective beam $\sigma$ and $\sigma'$, reduce intensity at experiment, but do not add noise

  For $\Delta\varepsilon/\varepsilon = \varepsilon_{cm}/\varepsilon_o <\sim 10\%$: **$\Delta y_{cm}$(rms) < ~0.3 $\sigma_y$** **$\Delta y'_{cm}$(rms) < ~0.3 $\sigma_{y'}$**

  **Note: can have frequency aliasing if don't obey Nyquist….**

- **Disturbance periods ≥ experiment integration time:**

  Orbit disturbances add noise to experiment

  For $\Delta\varepsilon/\varepsilon = \sim 2\sqrt{\varepsilon_{cm}/\varepsilon_o} <\sim 10\%$: **$\Delta y_{cm}$(rms) < 0.05 $\sigma_y$** **$\Delta y'_{cm}$(rms) < 0.05 $\sigma_{y'}$**

- **Disturbance periods >> experiment time (day(s) or more):**

  Realigning experiment apparatus is a possibility

- **Sudden beam jumps or spikes can be bad even if rms remains low**

  Peak amplitudes can be **> x5** rms level

# Beam Stability Time Scales – cont.

## Most demanding stability requirements:

- Orbit disturbance frequencies approximately bounded at high end by data sampling rate and a low end by data integration and scan times

**⇒ noise not filtered out**

## Data acquisition time scales:

- Most experiments average for 100 ms or more
- Some experiments average over much shorter times (e.g. 100 kHz)

**⇒ sensitive to synchrotron oscillations (~10 kHz)**

- Acquisition rates are increasing, averaging times decreasing

**MHz for turn-turn measurements**

**single-shot acquisition for pulsed sources (e.g. pump-probe)**

# Beam Stability Requirements - Summary

| Parameter | Present | Future trend |
|---|---|---|
| intensity stability | < 0.1% | < 0.01% |
| steering accuracy | < 5-10% $\sigma_{e-}$, $\sigma'_{ph}$ | < 2% $\sigma_{e-}$, $\sigma'_{ph}$ |
| beam size stability | < few % $\sigma_{ph}$ | < 1% $\sigma_{ph}$ |
| energy resolution | $10^{-4}$ | $10^{-5}$ |
| timing stability | < 10% bunch length | < 10% bunch length |
| min data avg time | order 1 ms | order 1 μs (ring)<br>single shot (FEL) |
| emittance | ~5-20 nm-rad | ~0.05-0.2 nm-rad |
| e- beam size (vert) | ~30-300 μm | ~3-30 μm |
| ph beam divergence | ~10-200 μrad | ~0.5-10 μrad |
| e- bunch length | ~10-100 ps | 1-100 fs (FEL) |
| e- position stability (vert) | ~1-5 μm | ~0.1-1 μm |
| e- angle stability | ~1-10 μrad | ~0.05- 0.5 μrad |
| e- bunch length stability | ~1-10 ps | ~10-100 fs (FEL) |
| e- energy stability | $< 10^{-4}$ ($\Delta\phi < 0.1^{o}$) | $< 5 \times 10^{-5}$ |

# Stability Tolerances

- Tolerance budget for electron beam parameters contributing to instability of a specific photon beam parameter can be derived from stability sensitivities, assuming random uncorrelated effects:

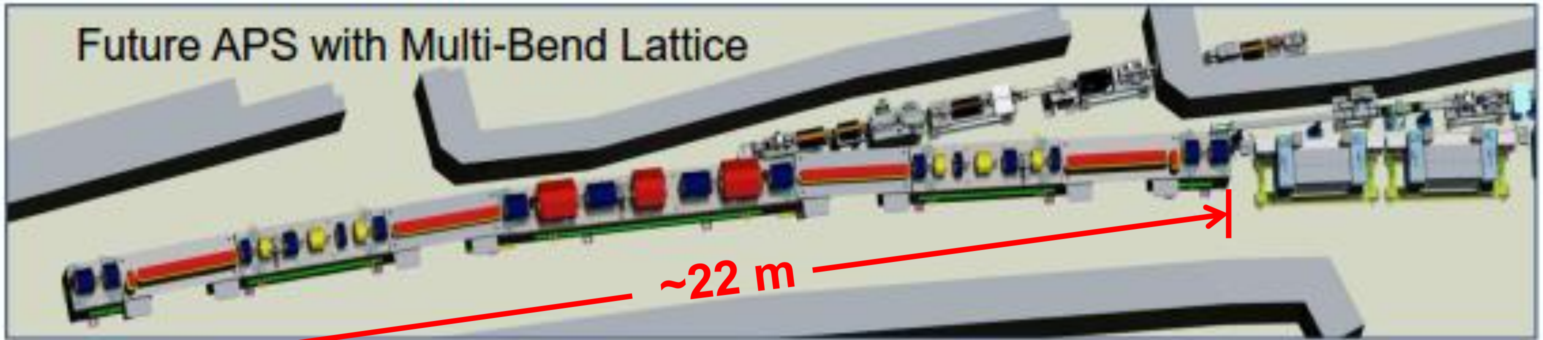
$$\sqrt{\sum_{i=1}^{n} \left( \frac{p_{tol}}{p_{sen}} \right)_i^2} < 1$$

$p_{tol}$ = tolerance for parameter p, $p_{sen}$ = sensitivity to parameter p

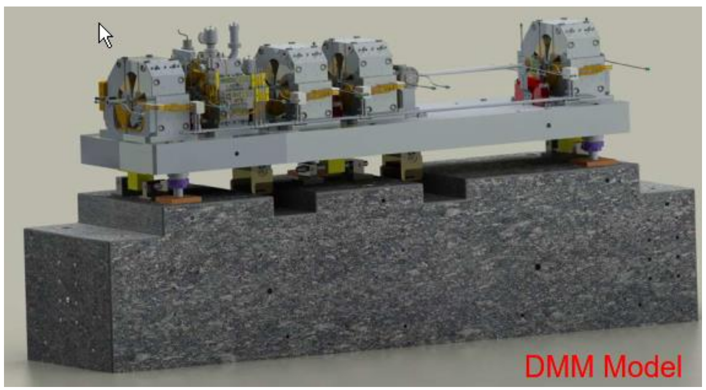
- e.g., to obtain <0.1% intensity stability, must reduce tolerances for orbit, beam size and energy stability below their sensitivity levels by ~$1/\sqrt{3}$ (0.57)

- Can increase tolerance for difficult parameters by reducing tolerance for easy parameters

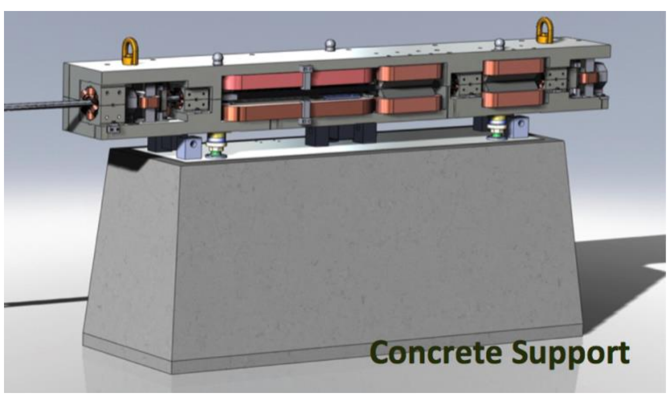
# Accelerator Lattice Stability




APS-U concept

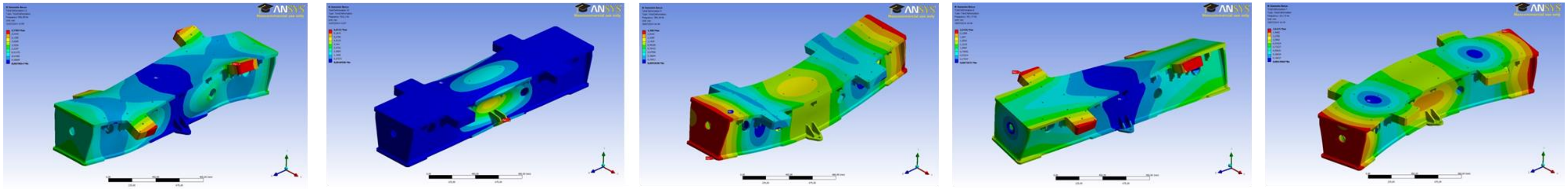



MAX-IV




# Magnet Stability

| Mode | Frequency [Hz] | Predicted by FEM [Hz] |
|---|---|---|
| Y-bending | 319 | 322 |
| Torsion | 333 | 352 |
| Z-bending | 354 | 354 |
| Plate membrane mode | 501 | |
| Second order Z-bending | 552 | |



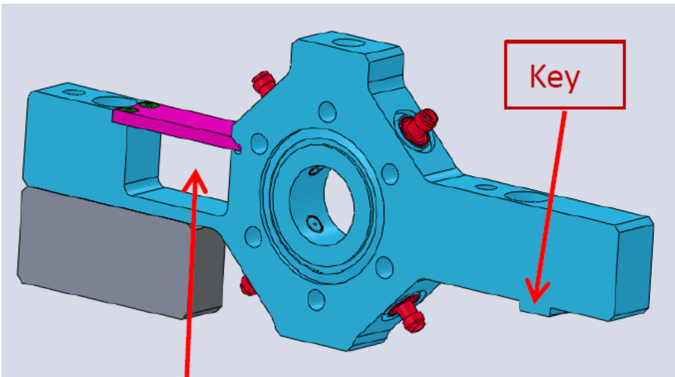
**Lattice amplification for uncorrelated gaussian distribution of N quad misalignments:**

$$A \approx \sqrt{\frac{N\overline{\beta}}{8}}\,\frac{\langle kl \rangle}{\sin \pi \upsilon_y} = \sim 10$$

**Can be reduced with rigid mounting of QFs and QDs on a girder – correlated motion**

# BPMs and Vacuum Chamber Components

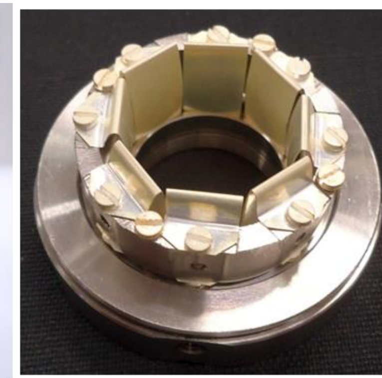
BPM: Stainless steel machined block, attached to the magnet.




Opening for the photon beam

MAX-IV BPM

- BPMs supported in midplane to reduce effects of thermal expansion
- Bellows are shielded to minimize impedance
- Flange joints are “gap-less” to reduce impedance

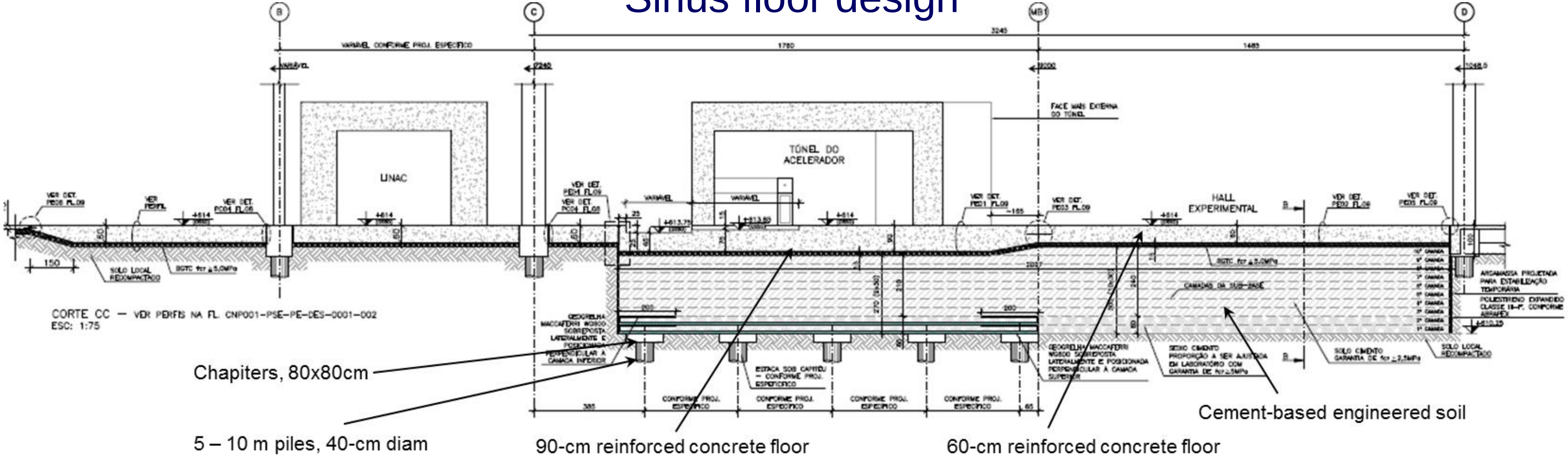


Similar to DAFNE design (omega stripe)

Sirius gapless flange, BPM block and bellows

# Building Stabilization

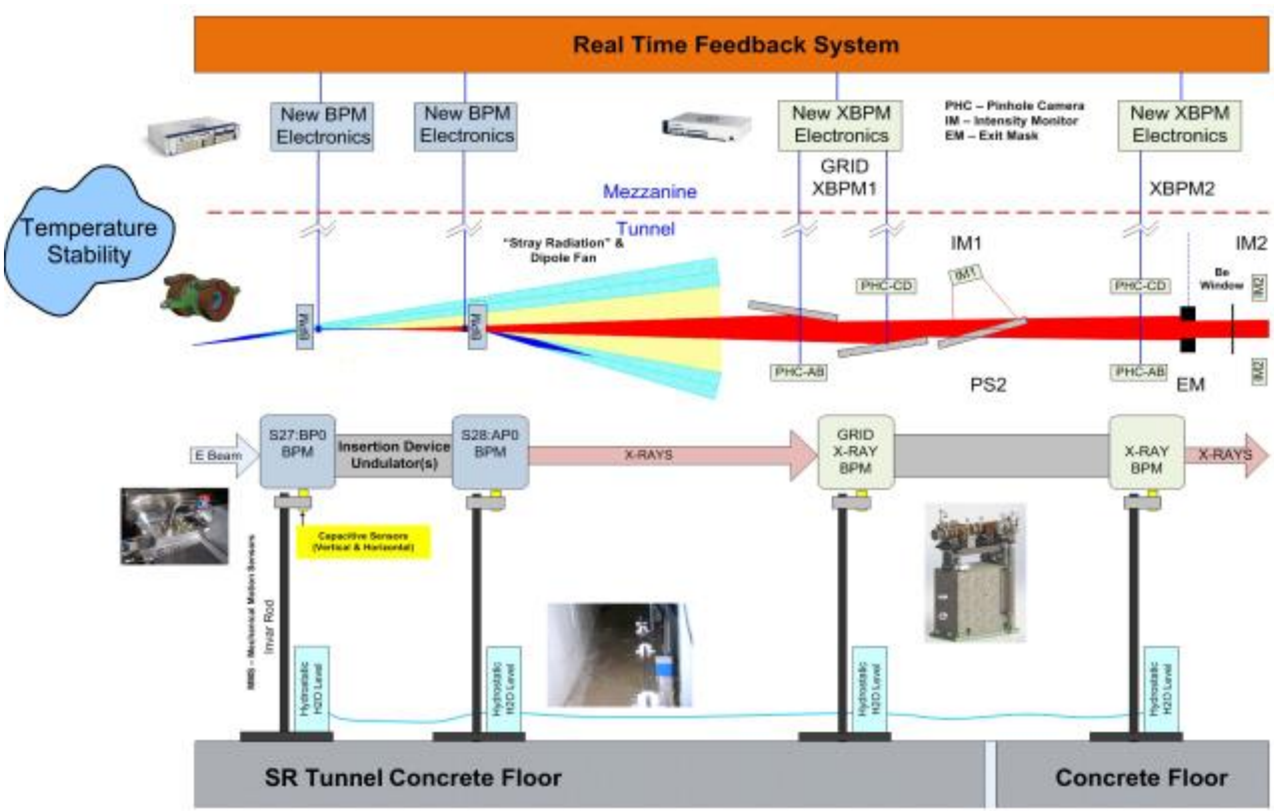
Sirius floor design




MAX-IV

- Tunnel floor and beam line floor design is not trivial
- Single-pour floor vs.segmented
- Understanding ground motion modes and finding ways to suppress them in the facility
- Tunnel temperature stability ~0.1 C

# Feedback and Damping Systems




APS orbit feedback

- Electron and photon BPMs
- Beam monitors and movers for critical beam line components (mirrors, monochromators, sample, …)
- Integrated accelerator-beam line orbit feedback systems
- Multibunch feedback
- Mode-damped RF cavities
- Landau damping cavities
- etc.

# 4GSRs (and FELs)

- Pointing stability of small beams over large distances
- Preservation of coherent wavefronts in X-ray optics
- …

# Conclusion

**Storage ring stability requirements are stringent:**

- intensity stability < 0.1%
- pointing accuracy < 5% beam dimensions
- photon energy resolution < $10^{-4}$
- timing stability < 10% bunch length

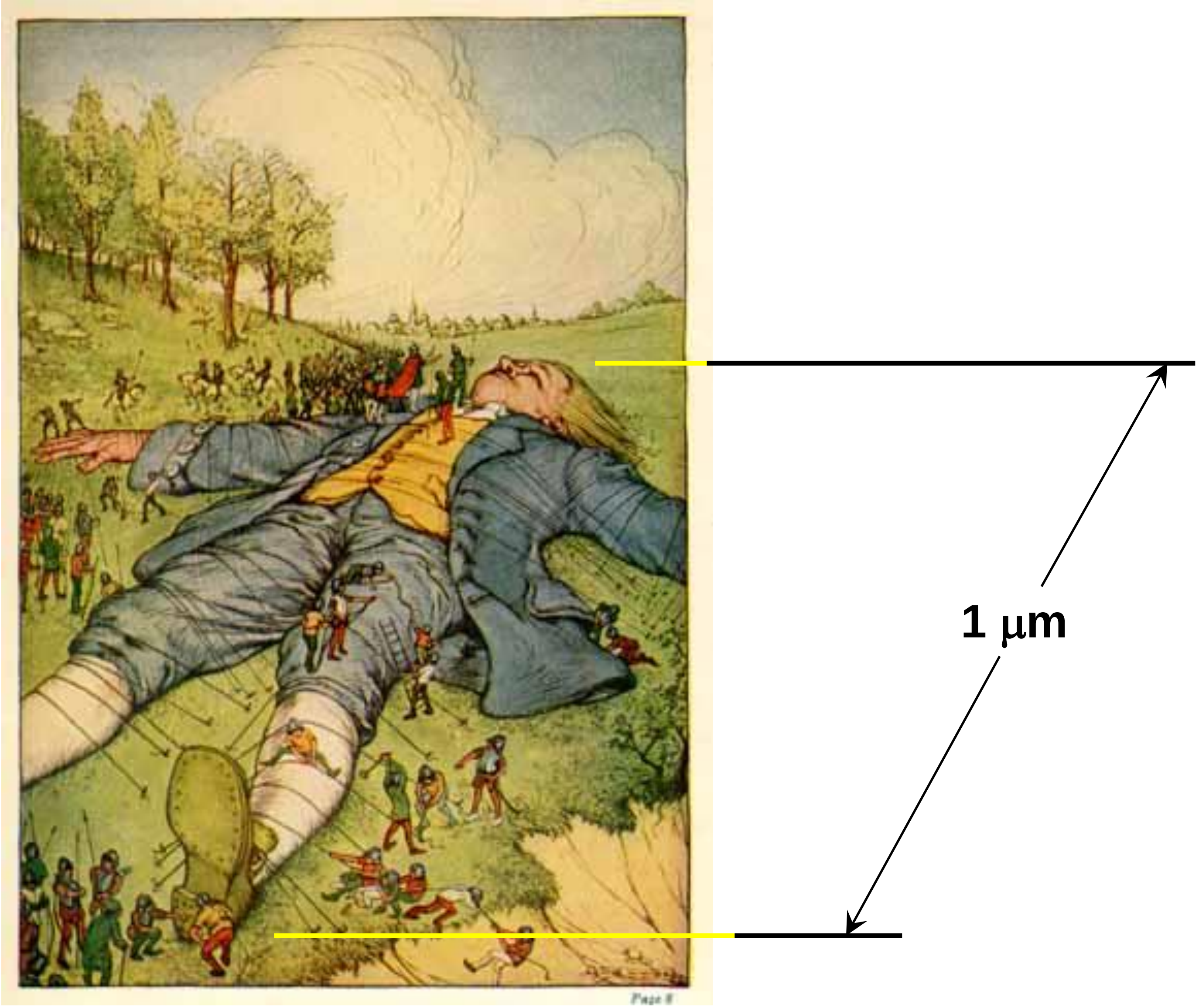
**Requirements are becoming more difficult to meet for 4GSRs:**

**x 5-10 more stringent stability**

- faster data acquisition time-scales
- fast-switched polarization, ID changes
- short bunch and other special operating modes

**Stability that can be reached by mechanical design alone is limited:**

- feedback is ultimately needed for accelerator and beam line components (integrated accelerator-beamline)
- demands for passive stability can be relaxed, possibly resulting in a lot of cost savings in facility construction


1 μm